The Role of Metal-on-Metal Bearings in Total Hip Arthroplasty and Hip Resurfacing

Review Article

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Abstract *Background:* The current role of metal-on-metal (MoM) bearings in hip arthroplasty remains controversial. The low wear offered by MoM bearings compared to metal-on-polyethylene and the possibility of a lower risk of dislocation with larger head sizes, encouraged a trend towards the re-introduction of the MoM bearing couple. However, recent evidence has shown that not all designs of the MoM bearing have been successful. *Questions/Purposes:* The purpose of this paper is to provide an update on the use of MoM bearings and address the following issues: (1) the reintroduction of metal-on-metal bearings in total hip arthroplasty, (2) the failure of metal-on-metal bearings in stemmed total hip arthroplasty, (3) the role of metal-on-metal hip resurfacing in modern orthopaedics and (4) metal-on-metal hip resurfacing versus total hip arthroplasty. *Methods:* A literature search strategy was conducted using various search terms in MEDLINE and Embase. The highest quality articles that met the inclusion criteria and best answered the topics of focus of this review were selected. Key search terms included ‘metal-on-metal’, ‘total hip arthroplasty’

and ‘hip resurfacing’. *Results:* The initial search retrieved 1240 articles. Twenty-two articles were selected and used in the review. *Conclusion:* Metal-on-metal hip resurfacing is still a suitable treatment option in specific patient populations with the appropriate implant design and surgical skill, while stemmed metal-on-metal total hip arthroplasty should be avoided in all patient populations. Continued follow-up of patients undergoing metal-on-metal hip resurfacing is critical in order to further understand the long-term outcomes of these patients and why certain complications tend to occur with this procedure.

Keywords metal-on-metal · total-hip arthroplasty · hip resurfacing · pseudotumor

Introduction

The use of metal-on-metal (MoM) bearings is no longer prevalent due to frequent reports of periparticular soft tissue masses, or pseudotumors [5, 12, 16, 21]; elevated local and systemic metal ion levels [3, 18, 24, 29]; and early failure rates seen in some implant designs [17, 27]. Although there has been a resurgence of the use of these bearings in the last 20 years, their use in stemmed total hip arthroplasty is not currently recommended based on the negative outcomes that have been reported in the literature [1, 4, 20, 27]. This leads to the question of whether MoM bearings have any role in the treatment of hip osteoarthritis. MoM hip resurfacing is an alternative to the traditional total hip arthroplasty (THA) in treating osteoarthritis in young patients. The perceived benefits of hip resurfacing include the preservation of the femoral neck and the avoidance of femoral canal violation, the ability to perform arthroplasty in patients with proximal femoral deformities or existing hardware in situ and a straightforward conversion to a total hip arthroplasty should

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it be necessary [13]. The large diameter of femoral components in hip resurfacing also allows for lower risks of dislocation and maintenance of normal femoral loading and stress. Despite these benefits, complications associated with hip resurfacing include femoral neck fracture, component loosening and soft tissue reaction to metal debris. Registry data has shown that MoM hip resurfacing is successful in certain patient groups; however, the use of MoM hip resurfacing in modern orthopaedics is still considered controversial [19].

The goal of this paper is to provide an update on the use of metal-on-metal bearings and address the following topics: (1) the reintroduction of MoM bearings in THA, (2) the failure of MoM bearings in THA, (3) the role of MoM hip resurfacing in modern orthopaedics and (4) MoM hip resurfacing versus total hip arthroplasty. This paper will thus elucidate the role of MoM bearings in current practice with background as to why they are no longer appropriate for stemmed THA, as well as clarify the role of these bearings in hip resurfacing and whether MoM hip resurfacing should play a role in modern orthopaedics.

Methods

In order to effectively address the various topics discussed in this review, a literature search strategy was conducted using various search terms in MEDLINE, and Embase. Only articles published in English between January 1, 2005 and March 1, 2015 were included. Focus was placed on articles published within the last 5 years with older articles only being included if the current literature was not available for the specific topic. Search terms included ‘metal-on-metal’, ‘total hip arthroplasty’ and ‘hip resurfacing’. Articles were selected based on their relevance to our research questions, the quality of the journal in which the article was published as well as the study design. Articles from the *Journal of Bone and Joint Surgery and Clinical Orthopaedics and Related Research* were prioritized over articles from other journals. Additionally, systematic reviews and randomized control trials were selected when possible.

Results

The initial search retrieved 1240 articles based on the search criteria specified in the methods section. The majority of the articles that were included were published within the last 5 years, with only two articles published before 2010. Though there were several articles that appropriately addressed the different review topics, the highest quality articles that met the inclusion criteria and best answered the topics of focus of this review were selected. Twenty-two articles were selected and included. Selection of these articles was based on the strength of the study design, the quality of the journal in which the study was published and the degree to which the study effectively addressed the review discussion topics. The findings and analysis of the included articles are presented according to the corresponding topic to which they relate.

Discussion

The Reintroduction of MoM Bearings in THA

MoM bearings were originally reintroduced over the last 20 years [14] because of their lower volumetric wear rates in comparison to conventional metal-on-polyethylene bearings [24, 31]. Additionally, these bearings have the potential to reduce wear-induced osteolysis and provide greater stability due to the option for larger head sizes [31]. Theoretically, the MoM bearing has several advantages based on the three principles of tribology: wear, friction and lubrication [7]. There are three distinct modes of lubrication described with respect to hip arthroplasty; boundary lubrication, which has the highest coefficient of friction; mixed lubrication; and fluid film lubrication, which achieves the lowest coefficient of friction. A typical coefficient of friction in the boundary lubrication regime is 0.1 where in fully developed fluid film lubrication, it can be as low as 0.001 [8]. Theoretical and experimental models have shown that MoM bearings act in the mixed lubrication and even the fluid film lubrication regime while metal-on-polyethylene bearings are limited to the boundary lubrication regime [8]. It was proposed that MoM bearings can operate in the mild mixed lubrication regime in which much of the applied load is supported by elastohydrodynamic films. Promotion of the most effective elastohydrodynamic films calls for the largest possible head diameters, reducing the clearance between the head and cup, minimization of surface roughness, good sphericity and minimal structural elastic deformation of the cup [8].

The Failure of MoM Bearings in Stemmed THA

Though these theoretical advantages exist for MoM bearings, results in the literature have demonstrated that outcomes for these bearings are quite poor in comparison to metal-on-polyethylene bearings. Smith et al. [27] found that MoM stemmed articulations gave poor implant survival in comparison to other implant options and recommended that MoM components not be used for total hip replacement. They also found that failure of the implant was related to head size, with larger heads failing earlier than smaller heads [27]. Additionally, Engh et al. [9] in their blinded, prospective randomized study with two MoM bearing groups and a metal-on-polyethylene control group found that cobalt and chromium ion levels in all blood sample types at the 5-year time point were significantly lower in the metal-on-polyethylene group than in each of the two MoM groups, with the exception of chromium in erythrocytes. Interestingly, the 28-mm MoM bearing appeared to perform better than the 36-mm MoM bearing with respect to metal ion levels at 5 years. The institutions that were involved in this study are now both avoiding the use of MoM total hip replacements [9]. Review of the Australian Orthopaedic Association Registry has also revealed that large head MoM THAs do not perform well in any patient and that larger diameter heads have higher revision rates [1].

There are a few potential explanations for the failure of MoM THA. One is related to metal debris generated at

locations other than the bearing surface. This unintended wear could result from sources such as implant impingement [22] or taper micromotion [24]. Recent implant retrieval studies have indicated the presence of corrosion at the stem-head junction of large-diameter implants [24]. Micromotion toggle caused by a force medial to the centre of the trunnion, made worse by a longer moment arm and increased frictional torque generated at the bearing surface, is thought to be the mechanism behind increasing wear and corrosion noted with increasing head size [10].

The development of soft tissue masses after MoM THA has been frequently reported as a complication [2]. Various studies have examined whether elevated metal ion levels are associated with the development of pseudotumors after MoM THAs. Bayley et al. [2] found no correlation between the presence of pseudotumor and any of the risk factors they examined including elevated metal ion levels, femoral head size and head-neck taper length, among others. This was an unexpected result since previous studies had reported an increased risk of pseudotumor development with increased metal ion levels [5, 16], which may indicate that patient-specific factors such as metal hypersensitivity may be more involved in pseudotumor formation than previously believed [2]. Based on conflicting results, more research may be necessary to examine the relationship between pseudotumor development and metal ion levels.

The Role of MoM Hip Resurfacing in Modern Orthopaedics

Hip resurfacing is the only feasible MoM bearing option, though metal ion complications that have been associated with MoM stemmed THA have also occurred in patients who have undergone MoM hip resurfacing: these reactions are limited mostly to some implant designs and patient factors [11]. The Australian Orthopaedic Association National Joint Replacement Registry shows that males who underwent hip resurfacing with large femoral heads (≥ 50 mm) have a lower revision rate than males with a THA [1]. Furthermore, the registry shows that the Birmingham Hip Resurfacing (BHR) system has the lowest revision rate compared to all other hip resurfacing implants when all patients and all sizes of implant are included, with an 8.4% revision rate at 13 years [1]. The BHR implant has shown outstanding survival rates, good functional outcomes, a low initial complication rate and excellent stability [23]. Sehatzadeh et al. [26] conducted a health technology assessment comparing the revision rates of hip resurfacing arthroplasty (HRA) assessing various implants using the National Institute of Clinical Excellence guidelines which outline that the best prostheses should have a revision rate of 10% or less at 10 years. The BHR was one of the three implants that met this criterion. The conclusion of their analysis stated that MoM hip resurfacing arthroplasty can be beneficial for properly selected patients, as long as the surgeon conducting the surgery has the appropriate skillset for performing the procedure [26].

However, current literature is varied with respect to reported outcomes of MoM hip resurfacing [20].

Outcomes of MoM hip resurfacing are influenced by a number of factors including implant positioning, implant design and the specific patient characteristics [28]. Analysis of revised MoM hips has demonstrated that revision is often related to high wear rates in the metal bearing surfaces, which can increase metal ion levels and potentially lead to undesirable tissue reactions [28]. One of the main factors believed to lead to these revisions is edge loading of the acetabular cup—when the maximum depth of the wear scar occurs at the cup rim or if the edge of the wear scar has a distinct boundary [28]. True edge loading occurs when the contact patch between the acetabular and femoral component extends over the rim of the cup, which leads to large increases in local contact pressure at the cup rim. Microseparation, impingement as well as break down of boundary lubricant film also result in similar patterns of wear as edge loading [28]. The material properties of the metal implant also impact the wear rate. Not all MoM bearings are treated in the same way, with some classified as ‘as-cast’ (high-carbide), some as ‘single-annealed’ (medium-carbide) and some as ‘double-annealed’ (low-carbide) [15]. Kinbrum and Unsworth [15] tested these three materials in a multidirectional pin-on-plate wear machine and found that the as-cast specimens showed the lowest wear rate while the double-annealed specimens showed the highest wear rate.

A potential complication of hip resurfacing includes elevated local and systemic metal ion levels in the blood and urine of patients and periprosthetic tissue reactions to wear particles [2]. Less than 1% of patients who have undergone MoM resurfacing develop an inflammatory response, and of those patients, some develop a more severe response, which is termed ‘pseudotumor’ [6]. The Canadian Hip Resurfacing Group [6] conducted a study that examined the prevalence of pseudotumor following MoM hip resurfacing at nine Canadian academic centres. Over a mean follow-up of 3.4 years, the study found that only four of the 3432 patients developed a pseudotumor, a prevalence of 0.1%. The authors concluded that more observation is necessary to identify what causes pseudotumors; however, based on their results, the prevalence appears to be very low over the short term [6]. Additionally, it is important to acknowledge that pseudotumors not only occur with MoM implants but also occur after metal-on-polyethylene total hip replacement [6]. In two 2012 case reports, one patient developed a pseudotumor after undergoing a metal-on-polyethylene hip arthroplasty [25] while the other patient developed one after a metal-on-highly cross-linked polyethylene hip arthroplasty [30].

MoM Hip Resurfacing Versus Total Hip Arthroplasty

Several published studies have reported promising early clinical results following MoM hip resurfacing, though most of these studies are limited by their lack of long-term results [20]. A 2014 systematic review, which included 236 studies, compared hip resurfacing versus THA in terms of early and overall revisions, adverse events as well as revision rates from their review to the revision

rates in four major joint registries [19]. The results were stratified by device market status in order to differentiate between devices that are still in use and ones that are discontinued. Based on the results of the review, revisions and reoperations were more frequent and occurred much sooner for MoM hip resurfacing, except when discontinued devices were removed from the analyses. Dislocations were more frequent in the THA group whether discontinued devices were included or not [19]. More long-term data with appropriate outcome definitions are necessary in order to further evaluate MoM resurfacing compared to THA [19] but the available data currently suggest that there is a role for MoM resurfacing in certain patient groups.

A 2013 cost-utility analysis compared MoM hip resurfacing to THA in young active patients with osteoarthritis in terms of the expected cost per quality-adjusted life-year (QALY) from a health care payer perspective [13]. In terms of the base case, MoM hip resurfacing was less expensive and had higher lifetime QALYs than THA with a mean difference in costs of −\$583 and a mean difference in QALYs of 0.079. THA did become less costly with higher lifetime QALYs than MoM hip resurfacing if cohort age was changed to 60 years instead of 50 years or if only women were assessed. The authors concluded that from an allocative efficiency viewpoint, there is not a preferred treatment option that can be identified on the basis of current cost-effectiveness data, but that on average MoM hip resurfacing was preferred to THA for younger and male patients [13]. It is still necessary to collect more long-term data, but at a minimum, these results do suggest that MoM hip resurfacing in male patients aged 50 years or younger has the potential to reduce costs as well as provide an increase in QALYs over THA.

The use of MoM bearings has changed significantly over the last 50 years, wherein it has been abandoned and reinitiated several times. Based on the current literature and the opinions of experts in the field of orthopaedics, stemmed MoM THA no longer has a role as a treatment approach. When MoM hip resurfacing is utilized in the appropriate population and performed by an experienced surgeon with the proper implant, MoM hip resurfacing is a suitable treatment option, and one that may prove to be more cost-effective than THA pending the collection and proper analysis of long-term data. Therefore, MoM bearings still have a role in modern orthopaedics. MoM hip resurfacing is most appropriate in young males with advanced osteoarthritis and large femoral heads. It is critical that current patients undergoing MoM hip resurfacing are monitored carefully and have their follow-up completed regularly in order to help elucidate the effectiveness of this procedure over the long term. Such results, when available, may once again change the role of MoM bearings in orthopaedics; however, based on the current data, MoM resurfacing has yielded positive outcomes in specific patient populations and is a procedure we should continue to evaluate and reassess.

Compliance with Ethical Standards

Conflict of Interest: David Sands, MSc, has declared that he has no conflict of interest. Emil H. Schemitsch, MD, FRCSC, reports personal fees from Smith & Nephew, Stryker, Amgen, Bioventus, Sanofi, Acumed and Zimmer, and Elsevier, outside the work.

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References

1. Australian Orthopaedic Association National Joint Replacement Registry. *Annual report*. Adelaide: AOA; 2014.
2. Bayley N, Khan H, Grosso P, et al. What are the predictors and prevalence of pseudotumor and elevated metal ions after large-diameter metal-on-metal THA? *Clin Orthop Relat Res*. 2015; 473(2): 477–484.
3. Bernstein M, Desy NM, Petit A, Zukor DJ, Huk OL, Antoniou J. Long-term follow-up and metal ion trend of patients with metal-on-metal total hip arthroplasty. *Int Orthop*. 2012; 36(9): 1807–1812.
4. Bolland BJ, Culliford DJ, Langton DJ, Millington JP, Arden NK, Latham JM. High failure rates with a large-diameter hybrid metal-on-metal total hip replacement: Clinical, radiological and retrieval analysis. *J Bone Joint Surg (Br)*. 2011; 93(5): 608–615.
5. Bosker BH, Ettema HB, Boomsma MF, Kollen BJ, Maas M, Verheyen CC. High incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement: A prospective cohort study. *J Bone Joint Surg (Br)*. 2012; 94(6): 755–761.
6. Canadian Hip Resurfacing Study Group. A survey on the prevalence of pseudotumors with metal-on-metal hip resurfacing in Canadian Academic Centers. *J Bone Joint Surg Am*. 2011; 93(Suppl 2): 118–121.
7. Dowson D. Bio-tribology. *Faraday Discuss*. 2012; 156: 9–30. discussion 87–103.
8. Dowson D, Jin ZM. Metal-on-metal hip joint tribology. *Proc Inst Mech Eng H*. 2006; 220(2): 107–118.
9. Engh CA, MacDonald SJ, Sritulanondha S, Korczak A, Naudie D, Engh C. Metal ion levels after metal-on-metal total hip arthroplasty: a five-year, prospective randomized trial. *J Bone Joint Surg Am*. 2014; 96(6): 448–455.
10. Fricka KB, Ho H, Peace WJ, Engh CA Jr. Metal-on-metal local tissue reaction is associated with corrosion of the head taper junction. *J Arthroplasty*. 2012; 27(8 Suppl): 26–31.e1.
11. Haddad FS, Thakrar RR, Hart AJ, et al. Metal-on-metal bearings: the evidence so far. *J Bone Joint Surg (Br)*. 2011; 93(5): 572–579.
12. Hart AJ, Satchithananda K, Liddle AD, et al. Pseudotumors in association with well-functioning metal-on-metal hip prostheses: a case-control study using three-dimensional computed tomography and magnetic resonance imaging. *J Bone Joint Surg Am*. 2012; 94(4): 317–325.
13. Heintzbergen S, Kulin NA, Ijzerman MJ, et al. Cost-utility of metal-on-metal hip resurfacing compared to conventional total hip replacement in young active patients with osteoarthritis. *Value Health*. 2013; 16(6): 942–952.
14. Innmann MM, Gotterbarm T, Kretzer JP, et al. Minimum ten-year results of a 28-mm metal-on-metal bearing in cementless total hip arthroplasty in patients fifty years of age and younger. *Int Orthop*. 2014; 38(5): 929–934.

15. Kinbrum A, Unsworth A. The wear of high-carbon metal-on-metal bearings after different heat treatments. *Proc Inst Mech Eng H*. 2008; 222(6): 887-895.
16. Kwon YM, Ostlere SJ, McLardy-Smith P, Athanasou NA, Gill HS, Murray DW. "Asymptomatic" pseudotumors after metal-on-metal hip resurfacing arthroplasty: prevalence and metal ion study. *J Arthroplasty*. 2011; 26(4): 511-518.
17. Langton DJ, Jameson SS, Joyce TJ, Hallab NJ, Natu S, Nargol AV. Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: a consequence of excess wear. *J Bone Joint Surg (Br)*. 2010; 92(1): 38-46.
18. Lavigne M, Belzile EL, Roy A, Morin F, Amzica T, Vendittoli PA. Comparison of whole-blood metal ion levels in four types of metal-on-metal large-diameter femoral head total hip arthroplasty: the potential influence of the adapter sleeve. *J Bone Joint Surg Am*. 2011; 93(Suppl 2): 128-136.
19. Marshall DA, Pykerman K, Werle J, et al. Hip resurfacing versus total hip arthroplasty: a systematic review comparing standardized outcomes. *Clin Orthop Relat Res*. 2014; 472(7): 2217-2230.
20. Matharu GS, Pandit HG, Murray DW, Treacy RB. The future role of metal-on-metal hip resurfacing. *Int Orthop*. 2015.
21. Matthies AK, Skinner JA, Osmani H, Henckel J, Hart AJ. Pseudotumors are common in well-positioned low-wearing metal-on-metal hips. *Clin Orthop Relat Res*. 2012; 470(7): 1895-1906.
22. Matthies A, Underwood R, Cann P, et al. Retrieval analysis of 240 metal-on-metal hip components, comparing modular total hip replacement with hip resurfacing. *J Bone Joint Surg (Br)*. 2011; 93(3): 307-314.
23. McNamara I, Manktelow A. (Iv) metal on metal hip replacement. *Orthopaed Trauma*. 2013; 27(5): 287-295.
24. Meyer H, Mueller T, Goldau G, Chamaon K, Ruetschi M, Lohmann CH. Corrosion at the cone/taper interface leads to failure of large-diameter metal-on-metal total hip arthroplasties. *Clin Orthop Relat Res*. 2012; 470(11): 3101-3108.
25. Murgatroyd SE. Pseudotumor presenting as a pelvic mass: a complication of eccentric wear of a metal on polyethylene hip arthroplasty. *J Arthroplasty*. 2012; 27(5): 820.e1-820.e4.
26. Schatzadeh S, Kaulback K, Levin L. Metal-on-metal hip resurfacing arthroplasty: an analysis of safety and revision rates. *Ont Health Technol Assess Ser*. 2012; 12(19): 1-63.
27. Smith AJ, Dieppe P, Vernon K, Porter M, Blom AW, National Joint Registry of England and Wales. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet*. 2012; 379(9822): 1199-1204.
28. Underwood RJ, Zografos A, Sayles RS, Hart A, Cann P. Edge loading in metal-on-metal hips: low clearance is a new risk factor. *Proc Inst Mech Eng H*. 2012; 226(3): 217-226.
29. Vendittoli PA, Roy A, Mottard S, Girard J, Lusignan D, Lavigne M. Metal ion release from bearing wear and corrosion with 28 mm and large-diameter metal-on-metal bearing articulations: a follow-up study. *J Bone Joint Surg (Br)*. 2010; 92(1): 12-19.
30. Walsh AJ, Nikolaou VS, Antoniou J. Inflammatory pseudotumor complicating metal-on-highly cross-linked polyethylene total hip arthroplasty. *J Arthroplasty*. 2012; 27(2): 324.e5-324.e8.
31. Zijlstra WP, Bos N, van Raaij JJ. Large head metal-on-metal cementless total hip arthroplasty versus 28 mm metal-on-polyethylene cementless total hip arthroplasty: design of a randomized controlled trial. *BMC Musculoskelet Disord*. 2008; 9:136-2474-9-136.